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Data Telemetry and Acquisition System for Acoustic Signal Processing Investigations

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13. ABSTRACT (*Maximum 200 words*)

This report describes the Satellite Vertical Line Array 32-channel system (SVLA-32) developed at the Naval Research Laboratory (NRL) for use during open ocean acoustic signal processing investigations for remote data collection and system control. This system was used during the TTCP Environmental Signal Processing Experiment (TESPEX) exercises in the summer of 1994, and demonstrated its ability to provide real-time collection of acoustic data over 32 channels, to perform onsite data formatting and the satellite transfer of that data to shore, and to allow full system command and control via the same satellite link. The system can be divided into the following subsystems: (1) the in-water subsystem: a hydrophone array, data acquisition unit, and umbilical cable, (2) the signal processing and recording subsystem, responsible for data formatting, storage to recording devices, and data dissemination, (3) the satellite communication subsystem, responsible for data telemetry and for remote control of the ocean buoy from the shore data processing center, and (4) the buoy subsystem, which includes a primary power generator and a buoy weather station. Capabilities of the current system are described as well as lessons learned during the TESPEX II program.

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CONTENTS

DATA TELEMETRY AND ACQUISITION SYSTEM FOR ACOUSTIC SIGNAL PROCESSING INVESTIGATIONS

I. BACKGROUND

Ocean acoustic measurements have traditionally relied upon autonomous data recording and/or the relaying of data to a support ship for data processing and recording, both of which have serious limitations. Autonomous recording suffers from the possibility of loss or contamination of the data that would go undetected in the use of an unattended system, providing no feedback to the user regarding data integrity or system performance. A support ship overcomes these limitations by providing operator attended data collection. However, the expenses in maintaining a support ship staffed with both engineering support and scientists on station during an acoustic experiment can be quite prohibitive. In addition, the quality of acoustic data collected can be corrupted by having a support ship in the area of testing .

Therefore, the challenge was to develop an acoustic data collection system that allowed full operator control and data access to the researcher without the complications and expense of hiring and staffing a support ship for the duration of the exercise.

The solution proposed by NRL was to develop a system that incorporated on-site signal processing and storage along with a satellite data telemetry capability for relaying the information to a distant shore location. This would allow the scientific staff and their equipment (data processing, imagery, etc.) to operate without the space constraints on personnel and equipment inherent to ship borne operations. An additional benefit would be that the acoustic data can be disseminated to data processing centers for near-real-time analysis by acousticians. The near-real-time analysis would allow the acousticians to modify the experimental parameters to produce optimum data sets.

II. INTRODUCTION

The SVLA system development was conducted under sponsorship from the Office of Naval Research, as part of the TTCP Environmental Signal Processing Experiment (TESPEX) program. TESPEX is a multinational experimental program that was conducted under the auspices of The Technical Cooperation Panel (TTCP). TESPEX included participation from scientific organizations in the U. S., Canada, New Zealand and Australia. Two experimental campaigns were conducted in the TESPEX program. The first experimental campaign, TESPEX I, was conducted off the east coast of the north island of New Zealand during April and May of 1993. The second campaign, TESPEX II, took place in the Arafura Sea off the north coast of Australia, during June and July 1994.

TESPEX I used a prototype SVLA system with four channels and a very simple data telemetry system. The "SVLA-4" system was powered entirely by batteries, and had a maximum of three days of continuous operation. (Power was partially

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complimented by three solar panels on top of the buoy.) The SVLA-4 system was installed on a surface buoy that was supplied by the New Zealand Defense Scientific Establishment (DSE), which was nicknamed the "Bumble Bee" buoy.

At the conclusion of TESPEX I, improvements and enhancements were made in the SVLA system. The system was outfitted with 32 acoustic hydrophones and a variety of environmental sensors. In addition, NRL designed a new buoy, developed for NRL by the Marine Physics Laboratory of the Scripps Institute (hereafter referred to as the NRL buoy). TESPEX II involved both the 4-channel and the 32-channel SVLA. The 4 channel system (SVLA-4) remained on the Bumble Bee buoy and the 32 channel system (SVLA-32) used the NRL buoy. Data collected by the SVLA-32 system was relayed to the shore data analysis center at the Northern Territories University (NTU) in Darwin, Australia. The buoy satellite telemetry equipment was installed into the 32-channel system, limiting the SVLA-4 system to autonomous recording.

Both SVLA systems used for TESPEX II were unique in that neither required a support ship to remain in the vicinity of the receiver once the acoustic array had been deployed. The SVLA-32 utilized satellite communications for remote control of the SVLA-32 system and for relaying acoustic data from the experiment site to the laboratory in Darwin, where scientists were able to receive and process the data. This allowed the ship towing the acoustic source to operate without regard for limitations typically imposed by line of sight (LOS) communications or tethered receive arrays. In addition, this experimental technique simultaneously allowed the scientists real-time access to a subset of the acoustic data and control of the SVLA-32.

This report will describe the SVLA-32 system, along with some details of the SVLA-4 system. The SVLA-32 system will be presented in four sections describing the component subsystems:

A. The in-water subsystem, consisting of the array, data acquisition unit (DAU), and umbilical cable,
B. The signal processing and recording subsystem, located on the buoy and on shore,
C. The satellite communication subsystem, and
D. the buoy subsystem, including the generator and weather station.

This report will describe the SVLA systems involved in this experiment, and enhancements that will extend the capabilities of these systems.

III. The 32-Channel Satellite Vertical Line Array

The SVLA-4 system used in TESPEX I provided a model for designing the 32-channel SVLA for TESPEX II. System enhancements were incorporated to improve reliability and to allow correlation of data between the two systems. A major modification to the original system was the addition of a GPS receiver to provide a time stamp for inclusion into the data stream. Having a GPS time stamp in the data for both the SVLA-4 and SVLA-32 systems enabled scientists to correlate the data to approximately 1/2 a second. Another improvement was the replacement of the kevlar tether cable used in

TESPEX I with a double-armored cable for improved reliability. (The tether cable electrical conductors remained unchanged.) The armored cable proved to be more reliable during the experiment, but also much more difficult to handle and deploy.

The SVLA-32 deployment scheme for TESPEX II is shown in Figure 1. During TESPEX II, Dansforth anchors, EG&G acoustic releases, and 454.5 Kg. (1000 lb.) weights were used at each anchor point. Figure 1 shows the Data Acquisition Unit (DAU), the surface telemetry buoy, and the hydrophone array of 32 sensors. The surface telemetry buoy provides power, cooling, and protection from the elements for the two Electronic Location Bays (ELB), each a five-foot tall, 19" wide rack. One ELB was used for satellite communication hardware and to gather buoy motion and weather data. The other ELB was used for signal processing and recording.

A. In-Water Subsystem

1. SVLA-32 array

Shown in Figure 2, the SVLA-32 array is a 163.1 meter (535 foot) electro-mechanical cable with hydrophones and non-acoustic sensors attached. The cable has an electrical core of 47 twisted pairs surrounded by a kevlar strength member and Dacron outer jacket. Nylon hair-type fairing was woven into the Dacron outer jacket to suppress cable strum. The array consisted of 32 hydrophones, 3 tilt sensor packages and a tilt/depth/pressure package. Each hydrophone required one twisted pair (of wires). The three tilt packages used two twisted pairs and the tilt/depth/heading packages used three twisted pairs for a total of 41 twisted pairs. The remaining six twisted pairs in the cable were spares. The hydrophones were mounted inside free-flooding protective PVC housings while the non-acoustic sensors were mounted in small pressure- proof housings.

The hydrophones used were two wire, dual sensitivity units. These were current mode devices, producing an output current proportional to the applied acoustic pressure. The output current was converted to voltage with a 1400 ohm termination resistor in the DAU signal conditioning circuitry, which achieved a nominal sensitivity of -176 dB re V/uPa. The sensitivity of the hydrophone was reduced by approximately 40 dB to -216 dB re V/uPa by switching the hydrophone's voltage supply polarity. The SVLA-32 included three two-axis tilt sensors and a combination two-axis tilt/magnetic heading/depth sensor package. The tilt packages were made up of a solid state tilt sensor with orthogonal axis sensitivity. The tilt/heading/depth package comprises a solid state orthogonal axis tilt sensor, a gimbaled solid state magnetic heading sensor and solid state pressure sensor. The tilt sensors have a range of +/-45 degrees.

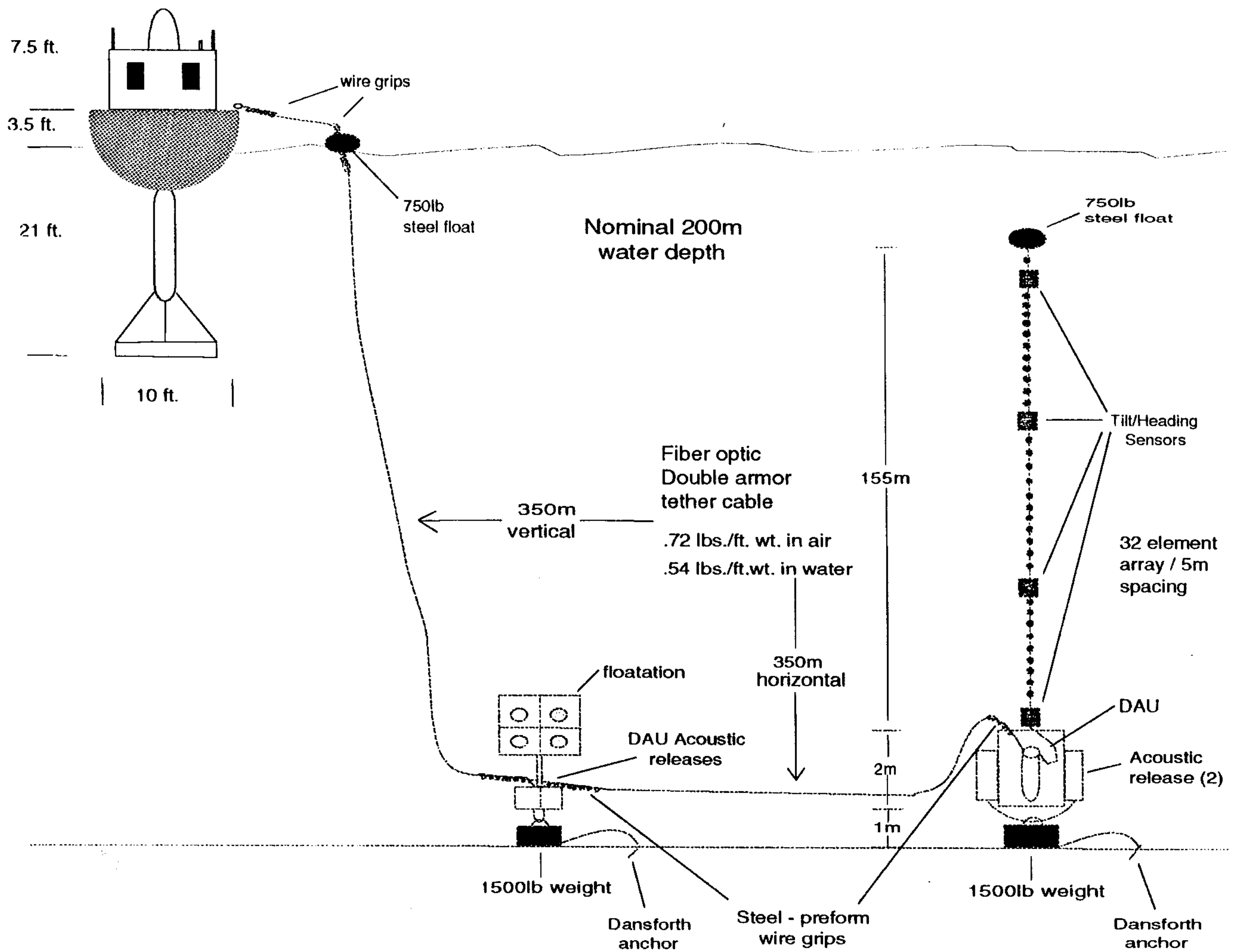
7.5 ft.
3.5 ft.
21 ft.
10 ft.
wire grips
750lb steel float
Nominal 200m water depth
750lb steel float
Tilt/Heading Sensors
155m
Fiber optic
Double armor
tether cable
.72 lbs./ft. wt. in air
.54 lbs./ft.wt. in water
350m vertical
32 element array / 5m spacing
floatation
350m horizontal
DAU
DAU Acoustic releases
Acoustic release (2)
2m
1m
1500lb weight
Dansforth anchor
Steel - preform wire grips
1500lb weight
Dansforth anchor

Figure 1

Figure 2. VLA–32

Figure 3. DAU

2. Data Acquisition Unit (DAU)

The DAU is pictured in Figure 3. The DAU is an electronic chassis mounted inside a cylindrical pressure-proof housing, which was enclosed in a protective aluminum framework. This pressure vessel is for deployment near the ocean bottom, and can operate to ocean depths of 914.4 meters (3000 ft). The aluminum housing was painted with an epoxy paint for protection against corrosion. The fixed bottom end cap provided mechanical mounting points to the framework. The removable top end cap included the mounting locations for the underwater connectors for the umbilical connector and array connector.

The DAU received the SVLA-32 sensor signals and transmitted a formatted digital telemetry stream to the surface buoy via the umbilical cable. The same cable provided the DC power from the surface buoy. Hardware switches in the DAU set the number and bandwidth of the hydrophone data channels. The format and bit rate adjusted automatically in accordance with the selected settings. The hydrophone signal conditioning circuits utilized delta sigma converters, which include an integral anti-aliasing filter which automatically changes corner frequency in accordance with the bandwidth switch setting. For TESPEX II, the system was configured for a hydrophone bandwidth of 4096 Hz, yielding a 4.7 Mbit data rate. (4096 X 2 (sampling rate) X 16 bits X 32 channels, plus engineering & packet overhead.) The system was data bus organized and consisted of a series of circuit boards sharing a common backplane.

Array configuration commands were sent remotely via the satellite telemetry link, permitting real-time configuration and control of the DAU. Commands were accepted from the buoy electronics via the umbilical cable and allowed modification of DAU operating parameters, including individual channel gain, hydrophone sensitivity, calibration signal activation, and pre-emphasis ON/OFF control. Calibration signals included analog and digitally generated sine waves and white noise input to the hydrophone circuitry.

3. The Umbilical Cable

The umbilical cable used is a double-armored electro-optic-mechanical cable. It has a 3409.1 Kg (7500 lb.) working load and a 13636.4 Kg (30,000 lb.) breaking strength. The cable core is a polyurethane jacketed cable consisting of both copper wires and multi-mode fibers. The copper conductors provided DC power to the DAU and passed DAU configuration commands from the surface buoy. The fibers provided a path for the digitized acoustic data to the buoy and were protected by a small stainless steel tube in the center of the core. Each end of the 1136.4 meter (2500 ft) cable was terminated in a small diameter pressure proof cylinder which housed the fiber optical/electrical conversion electronics. The cylinder for the DAU end converted electrical data signals to optical signals, and the buoy termination produced the opposite conversion. The multi-mode fibers were terminated with standard (ST) connectors. Four spare fibers were provided. An underwater connector at each end provided connection to the DAU and buoy bulkhead connectors from the electro-optic cylinders.

B. Signal Processing and Recording Subsystem

The Signal Processing and Recording Subsystem was both on land and housed on the surface telemetry buoy in an ELB. The buoy system consisted of an AC power regulator/conditioner, system power supply, VME computer system, 4 mm Digital Audio Tape (DAT) recorder chassis and Control Interface Board panel (CIB). The subsurface DAU transmits the digitized hydrophone and status data to the surface telemetry buoy. There, an on-board computer processes and records the data, forwarding a subset of the data to the satellite communications (SATCOM) ELB for transmission to a shore data processing station.

Both the buoy and shore/ship stations, shown in Figures 4a and 4b, were VME-based computer systems operating under the VxWorks real-time operating system. Each system shared a common hardware and software architecture but differed somewhat in specific functions performed within that architecture. The surface buoy computer accepts the DAU's high speed serial bit stream (4.7 Mbps), performs real-time digital signal processing to baseband the data, records data on 4 mm DAT tapes and forwards a subset of the data to the SATCOM ELB for transmission to shore. The shore station accepts a 19.2 kbps serial bit stream from the SATCOM receiver and relays this data to several workstations over a local Ethernet for display, archiving and scientific data processing. The common architecture, as well as the buoy and shore systems, are described in more detail below:

1. Common Hardware Architecture

The hardware architecture of the shore and buoy systems is based around a VME backplane running the VxWorks operating system. The buoy system VME hardware described below is a superset of the shore VME computer. The VME computer system was housed in a 19-inch rack mountable, 10 slot, 6U card cage chassis, and was comprised of a hard drive and the following 6U VME cards:

SLOT #	VME Board Description
1	Force Model 2CE-CPU Sparc CPU board
2	Bancomm Model bc637vme GPS board
3	Pentek Model 4270 quad C40 DSP board
4	Berg Model 4416-V PCM Simulator board
5	Berg Model 4411-VS PCM Decommutator board

The VME computer accepts DAU data at the rate of 4.7 Mbit/sec into the Berg Pulse Code Modulation (PCM) Decommutator board. The Force Sparc CPU holds software written in the C programming language running under the VxWorks real-time operating system. It interfaces to the Berg PCM Decommutator board, which searches for the embedded synchronization word in the data and re-assembles the data frames. The data is formatted further, then passed on to the Pentek DSP board where a 128 Hz wide window within the acoustic bandwidth of the data is band-shifted to baseband.

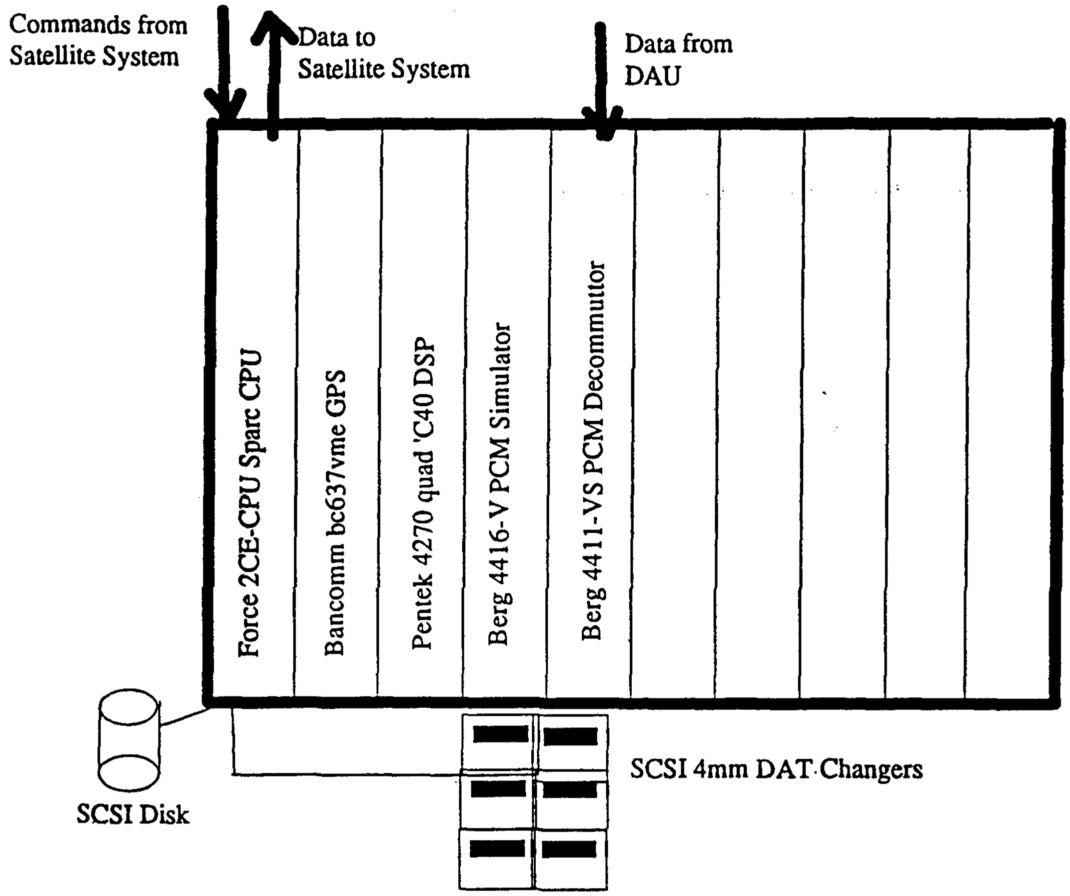

Figure 4A. Buoy Hardware Block Diagram

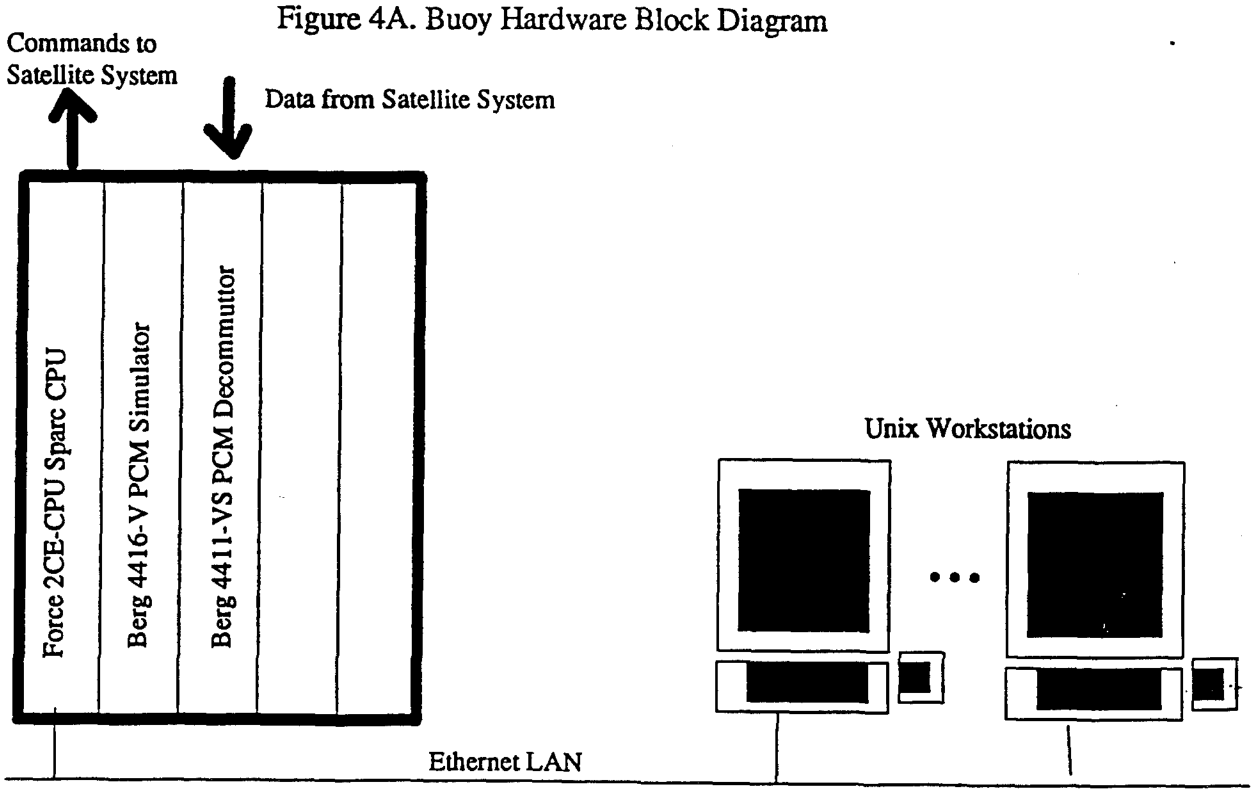

Figure 4B. Ship/Shore System Hardware Block Diagram

The window center frequency can be selected from shore using commands sent viasatellite downlink. The band-shifted data is recorded on a DAT 4 mm tape drive via the SCSI interface.

All power and data connections go through the CIB panel, where they are routed to the correct location. The CIB panel accepts the system 70 VDC from the power supply and provides power to the VME chassis and DAT chassis as well as power and signal connections to the DAU. It receives downlink commands from the SATCOM subsystem and routes the commands to the DAU and Force SPARC VME board. The CIB panel also controls power to the DAT 4 mm tape drives. Only one recorder is powered on at any time to conserve power. When a DAT drive is nearing the end of its recording capacity, the CIB electronics (on command from the SPARC VME board) sequences power to the next DAT drive for continuous data recording. The DAT chassis houses six Conner 4584NP Python autoloader DAT drives, each with a four tape cartridge yielding a total of 24 DAT tapes. The total storage capacity is 48 Gbytes. The recording capacity of the six DAT drives is approximately 16 continuous days, at the recording bandwidth of 128 Hz per channel. To extend the experimental campaign duration beyond 16 days, the system can operate in autonomous data collection mode only, or the DAT drives can be remotely turned on/off to extend record time.

Data from two of the 32 channels, user selectable via satellite downlink commands, is sent to the satellite modem in the SATCOM ELB for transmission to shore. Data sent via satellite includes engineering data (tilt, depth, heading, etc.) as well as the acoustic data from two of the 32 hydrophones. GPS time and position is updated continuously and included in both the recorded and transmitted data.

2. Common Software Architecture

Both the buoy and shore computer systems were designed to accept and process a continuous stream of digital data. The buoy system accepts the DAU bit stream and the shore system receives the satellite telemetry bit stream. Upon entering the processing system this continuous stream of data is first blocked or "framed" into segments of data and then these frames are passed through a series of processing stages in an assembly line manner. In order to maintain real-time processing, all frames must successfully pass through all processing stages without data loss or buffer overflow between successive stages. Processing systems of this type can be constructed in software by linking successive processing tasks with shared memory buffers. A diagram of this type of system is shown in Figure 5.

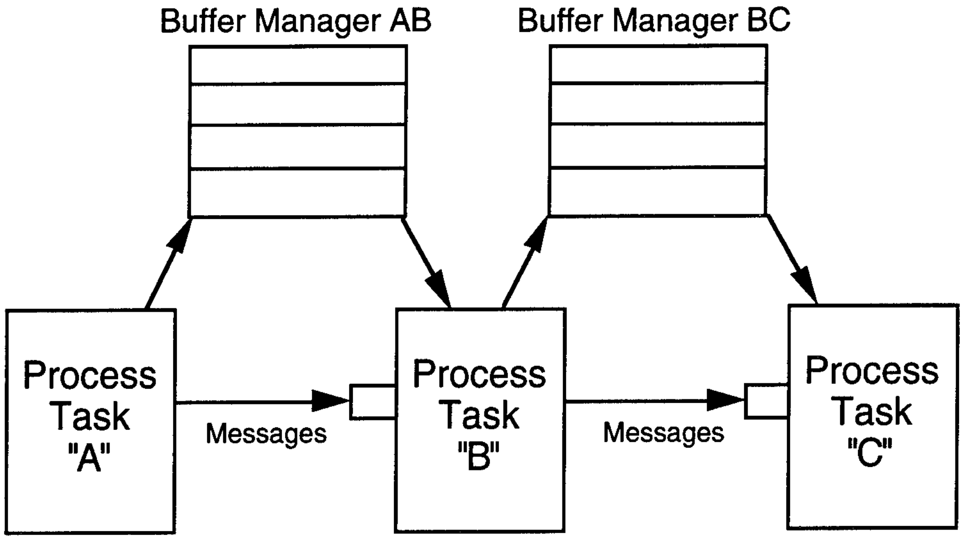

Figure 5: A Multi-stage Processing System. This system is used on both the buoy and shore software architectures to maintain real-time processing without data loss or buffer overflow between successive stages. Shown are the two types of software objects, processing tasks and buffer manager tasks.

The system is made up of two different types of software "objects"; processing tasks and buffer manager tasks. Processing tasks perform some type of operation on the data, such as FFT's, archiving to disk, or graphic display generation. Buffer manger tasks hold the frames of data between processing tasks and do not perform any operations on the data.

Essential to the overall operation of this system is the ability for the objects to communicate with each other by passing "messages". For example, when processing task A has completed processing a frame of data, it sends the output data frame to buffer manager AB. Task A passes a message to processing task B requesting task B to process the frame of data being held by buffer manager AB. Process synchronization, scheduling and buffer management are simplified by the fact that each task can "queue-up" several messages and associated input data frames. The buffer manager will retain the data frames for the queued messages until the processing task reads the data from the buffer manager.

This object-oriented architecture provides a very modular, building-block approach to configuring different real-time processing systems. Both the buoy and shore system software were built on top of this architecture. The multi-tasking, message queue and memory management facilities of the VxWorks real-time operating system are ideally suited for implementing this software architecture. Figures 6 and 7 are diagrams of the buoy and shore system software configurations, respectively.

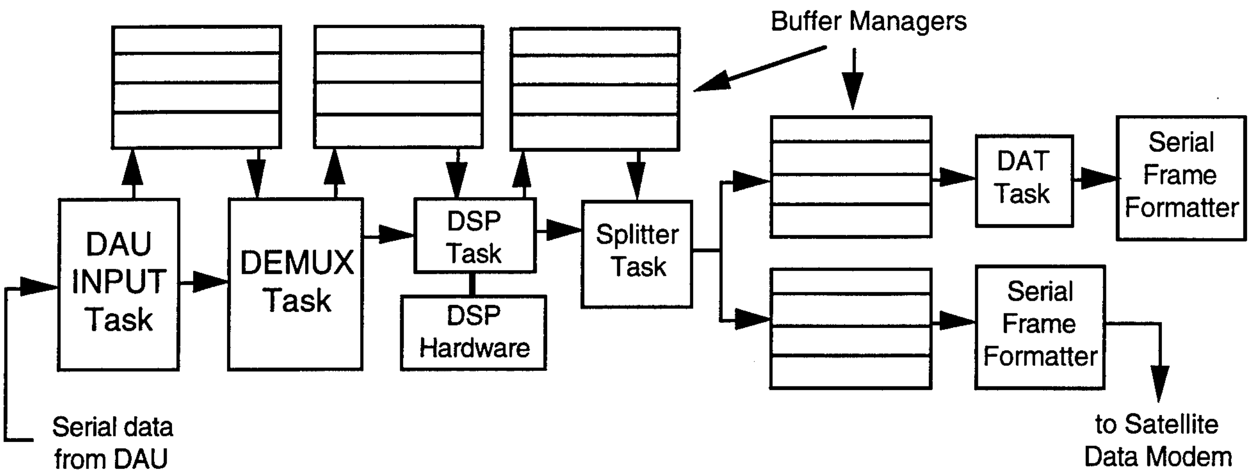

Figure 6: Buoy Software System

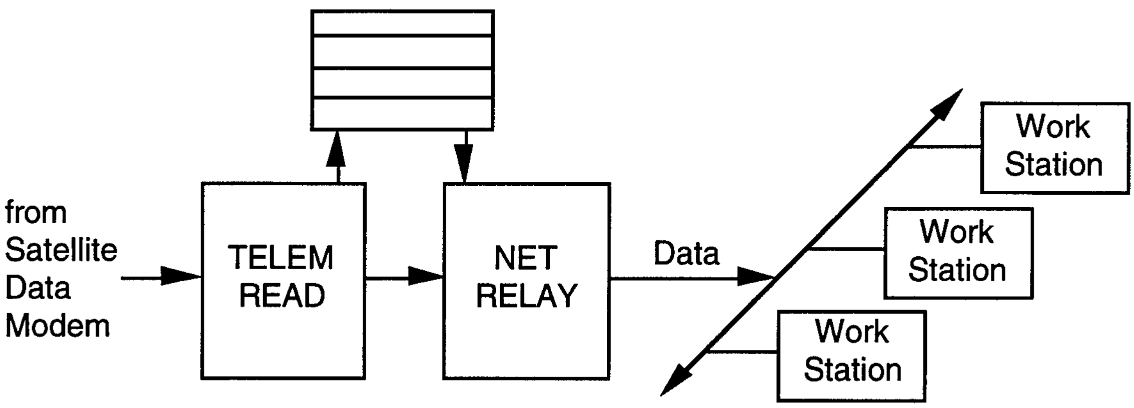

Figure 7: Shore/Ship Software System.

The specific functions of the processing tasks are as follows:

DAU INPUT: Accepts serial bit stream from subsurface DAU through a decommutator interface, performs synch-detection and assembles frames of data and writes them to buffer manager

DEMUX: Performs "corner-turning" on frames of data, re-arranging data from channel consecutive to sample-consecutive. Extracts ancillary data (pressure, tilt, heading, etc.) from the DAU data stream.

DSP: Provides a client/server software interface to a quad Texas Instruments 320C40 DSP-processor board. The DSP board performs basebanding and sample rate conversion on all 32 hydrophone channels. A selectable 256 Hz band of data is bandpass filtered and shifted to DC, reducing the required sampling rate by a factor of 16.

SPLITTER: Essentially a "Y - connector", providing identical feeds of data to the DAT and Serial Frame Formatter (SFF) tasks. This allows the DAT and SFF tasks to operate independently without concern for coordinating buffer management between multiple tasks.

DAT: Manages the DAT drive changer and records the basebanded data on the DAT tapes

SFF (Serial Frame Formatter): Selects data from 2 of the 32 basebanded channels for telemetry to shore, constructs a serial bit stream from this data and sends it to the satellite data modem.

Other background tasks not shown in the diagram are:

GPS: Continuously reads GPS time and position and provides this information to the other tasks where it is inserted in each data frame.

DOWN LINK: Reads remote control commands from shore station and sends these commands (packaged in messages) to the appropriate processing task(s). Remote commands include such operations as startup, shutdown, drive and tape selection, center frequency of the bandpass filter, etc.

At system startup, all processing tasks and buffer managers are initialized and the DAU INPUT task enters a "free-run" mode, where it continuously reads the incoming DAU bit stream, assembles frames of data and passes them to subsequent processing tasks. All other tasks enter a "wait" mode, remaining idle until they receive a message (and frame of data) from the previous stage, process the frame and pass it on to the next task. At any given time there are several frames of data moving through the system, each at a different stage of processing.

3. DSP Basebanding Algorithm

Bandwidth limitations of the telemetry link and DAT tape drives prevent telemetry and recording of the hydrophone time series at the full DAU sample rate of 8192 samples per seconds per channel. A basebanding DSP algorithm is applied to all hydrophones to overcome these limitations and allow acquisition of band-limited acoustic signals up to 4 kHz. The algorithm performs frequency translation, applies a 128 Hz wide digital filter (both positive and negative frequencies are passed, resulting in a 256 Hz total bandwidth) and subsamples the resulting signal to reduce sampling rate. The output data is a complex time series sampled at 256 complex samples per second, representing the 256 Hz band. The digital filter and decimation is actually performed in three successive stages. A commercial digital filter design package was used to optimally select intermediate decimation factors and filter lengths. The result was a three-stage filtering/decimation process, which was more computationally efficient than a single-stage filter and decimation process.

4. Shore Station Software Configuration

The processing stages of the shore station software for the DSP and recording subsystem were:

TELEM READ : Reads the incoming serial bit stream from the Satellite Data Modem and assembles frames of data

NET RELAY : Sends the frames of data to other workstations via standard TCP/IP sockets.

Shore station operation is as follows: Data frames are assembled by the TELEM READ task and transmitted to other networked workstations by the NET RELAY task (via TCP/IP sockets). Server programs executing on the networked workstations accept the incoming data and perform a particular task, such as archiving to disk or generating real-time displays of the data. Once the data is written to disk files, the data is available for scientific data processing and analysis. The modular design allows many configuration options, as well as future enhancement with minimal development effort. The existing software "objects" can be reconfigured or combined with new objects to accomplish other requirements. For example, data could be archived on DAT tapes at the shore station by attaching DAT drives and spawning a DAT task during the shore station's initialization. Other telemetry systems can be used (e.g. T1, ATM, Frame-relay) by replacing the Serial Frame Formatter task with a task to support a different physical link layer.

C. Satellite Communication (SATCOM) Subsystem

The SATCOM subsystem, shown in Figure 8, provided a medium data rate (19.2 kbps), half-duplex, two-way communication link from the buoy to the shore location. This enabled real-time acoustic data and status information to be relayed from the buoy to shore, as well as forwarding information requests and configuration changes from the shore site to the buoy SATCOM subsystem.

The SATCOM subsystem on the buoy and the shore station (shown in Figures 9 and 10 respectively) used common hardware for many of their components. Identical models of audio frequency shift keyed (FSK) modem and the radio frequency (RF) modems were used at each location. The buoy subsystem consisted of a satellite transceiver (a Navy ARC-187), a hemispherical radiator antenna system, two satellite data modems, and an embedded controller. The shore station used the more powerful Navy WSC-3 as a satellite transceiver.

Different antennas were used at each site. The buoy used a hemispherical radiator antenna system with a gain of approximately 1.5 dB. The antenna is located on top of the buoy radome, about 3 meters above the deck of the buoy. The shore site system used a monofilar helix antenna with a gain of approximately 8 dB.

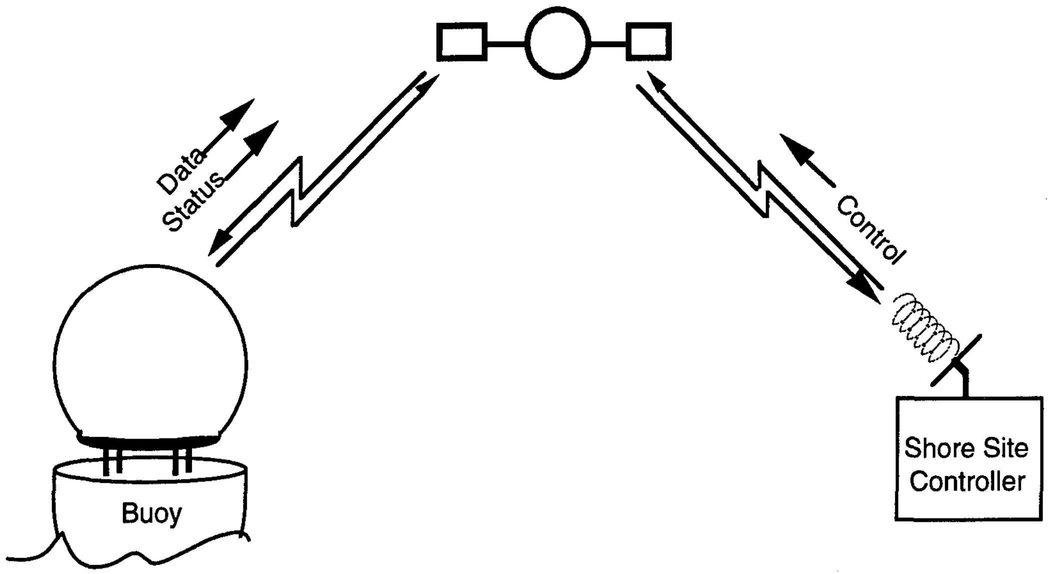

Figure 8: NRL Data Telemetry System. All transmissions of status and/or data by the buoy are initiated by the controller. System is operated in half-duplex.

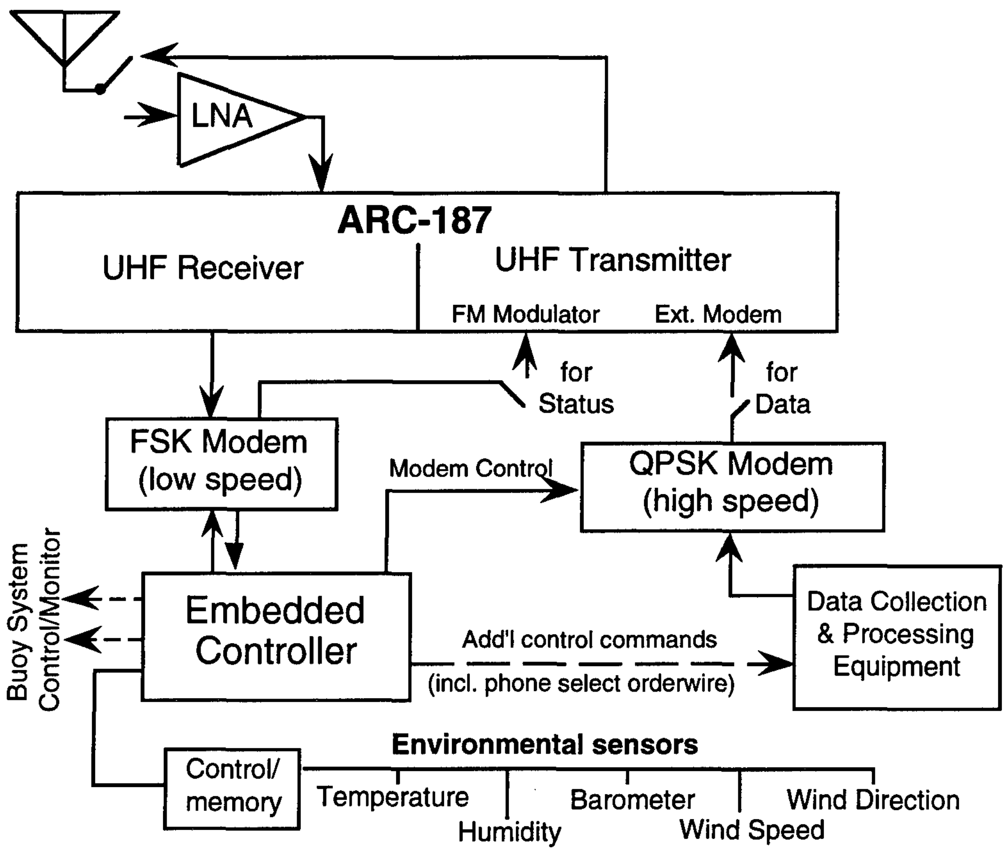

Figure 9: The buoy telemetry configuration uses the QPSK modem for sending acoustic data to the shore , and the FSK modem for transmission and reception of control information. Enviromental sensors are montored by the embedded controller, which passes that information back to shore as part of the status message.

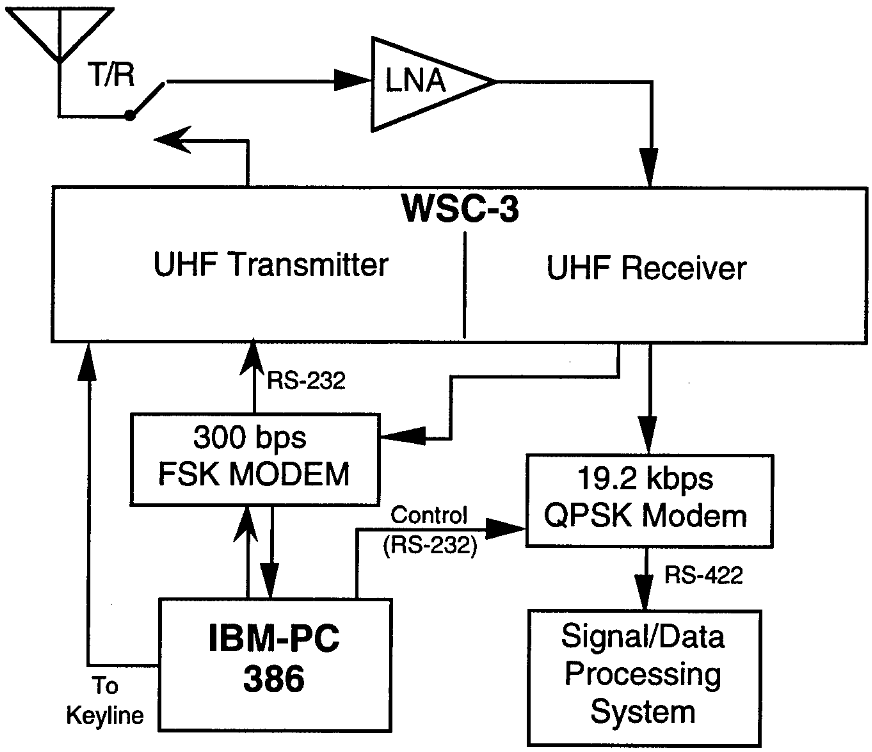

Figure 10: Data Telemetry System Configuration, Shore station. System controlled by PC running NRL software. Two modems provide both robust system control (FSK) and high data throughtput (QPSK).

The communications link could also be operated as a single frequency, line of sight (LOS) mode. This was quite useful during system checkout and deployment, when a "shore station" configuration was installed on a support ship, allowing engineers and scientists in the field to interact with the buoy electronics without boarding or retrieving the buoy itself.

1. Dual Modem Configuration

The two-way, half-duplex network between the shore and the buoy SATCOM subsystem utilized two modems: a QPSK modem, which operated at 19.2 kbps and a low data rate, FSK modem operating at 300 baud. The QPSK modem handled the transfer of the acoustic data from the buoy to shore, and the FSK modem was used in the two-way command and response ("request" and "status") traffic. Both sets of traffic utilized the same traffic in a time division multiplexing (TDM) configuration.

The request and status blocks, described in greater detail below, added up to a small number of bytes (less than 50). The FSK modem was selected for this data stream due to its ability to lock onto the receive data stream much faster than was possible with the more sophisticated, high data rate satellite QPSK modem, thereby increasing the reliability of effectively controlling and evaluating the buoy SVLA-32 system. Using the two-modem approach allows the system to exchange request and status blocks between shore and the buoy quickly, configuring the buoy system for the next experiment sequence, and (if desired) requesting the buoy system to transmit acoustic data for the next N minutes, where N could range from 1 to 129 minutes.

The QPSK modem, an SDM-8000, manufactured by EF Data, was responsible for the acoustic data traffic. The operating data rate of 19.2 kbps was driven by the available channel bandwidth on the UHF satellite system used for this test, the Navy's FLTSAT system. Experiments were done with the satellite at NRL that extended this data rate to 38.4 kbps, but this data rate was believed to be a higher risk for co-channel interference on the satellite. In addition, the 38.4 kbps was attained with a 7/8 encoding rate, which was less robust than the half-rate encoding used at 19.2 kbps.

A condition of the QPSK modem was its requirement for approximately two minutes for synchronization to the received data stream before the acoustic data could be recovered and ported to the evaluation tools on shore. This had an affect on the TESPEX test plan, and further illustrated the need for the separate, low data rate link.

2. Buoy Subsystem controller

The buoy communication subsystem was controlled by an 386 IBM PC clone. An analog-to-digital converter card was installed into the controller for monitoring the available generator voltage and the fuel level on the buoy. Control for the transceiver and switching the appropriate modems in and out of the system was accomplished through the controller's parallel port. The controller could also configure the RF modem and toggle it's power on and off, and was responsible for forwarding commands to the CIB panel (see section III B, above).

3. Software

The buoy software, designed and developed by NRL, controlled all aspects of the communication subsystem, including output power of the transceiver and modem selection. All communications were initiated by the shore controller. The buoy system operated only in a response mode to commands from shore, initiating no communication on its own. This eliminated the need for time synchronization between the two systems and also reduced the power consumption of the buoy system. Upon request for transmission, the buoy would respond with either information on the condition of the buoy communication subsystem (i.e., "status"), or with acoustic data.

The computer (an IBM-PC clone) on shore allowed the scientists to control the functioning of the array and buoy communications system, and displayed buoy system operating parameters on screen for personnel on shore. The PC software was designed to allow the scientists to send out a request for a block of acoustic data (from 1 to 129 minutes) or for buoy status. The operator could also request that data transmission begin at a particular time of day, but this option was never used in normal operation.

NRL-designed software at the shore site allowed the user to control every aspect of the buoy communication subsystem remotely. Below are the parameters sent in the request message from shore to control the buoy communication subsystem and the array electronics. Each parameter's value was represented as a hexadecimal character in a single byte, except for the DAU "word", which required five bytes.

Buoy Transmitter Power	Hi or Low (65 W or 30 W)
Start Time (hour)	00 to 23
Start Time (minutes)	00 to 59
Data Block Length(minutes)	00 to 129
Mode of Operation	standby, send status only, or send data and status
Continue/Start Transmitting immediately?	Yes or No
Power to SDM modem?	Yes or No
Reset?	Yes or No
LOS or SATCOM	LOS vs. SATCOM
DAU control word	[char1] [char2] [char3] [char4] [checksum]

Use of the FLTSAT satellite dictated that our system be capable of vacating the channel within two hours of notification. Therefore, the maximum block of time for data transmission was set at 129 minutes. Recalling that the RF modems required as much as two minutes to synchronize when a link was established, it was found that the shorter the down time of the buoy transmitter, the quicker the re-synchronization. To minimize the dropouts in data transmission (since such calls to vacate were never received), the shore computer software could be configured to execute a "roll over"; as soon as the buoy system had ceased transmitting and gone into receive mode, the shore station would automatically send an immediate request for another data block. The automatic roll over feature minimized the dropouts between blocks of data and cut the re-synchronization time to as little as twenty seconds.

D. Buoy Subsystem

The buoy used during TESPEX II for the SVLA-32 was designed by Richard Harriss, Marine Physics Laboratory, Scripps Institute of Oceanography, according to NRL specifications. The primary design goals were:

- to provide a "stable" platform for high bandwidth satellite communication,
- to be deployable from most ships of opportunity, and
- to provide adequate power and protection for electronics housed on the buoy for at least 30 days of operation.

The buoy, pictured in Figures 11 and 12, was successfully deployed from the FRV Southern Surveyor, and operated for the duration of the experiment. The buoy was outfitted with a generator, air conditioning, two electronic location bays (ELBs), a weather station, and motion sensors. The buoy, with ballast and radome, is approximately 30 feet tall and 10 feet wide, weighing 7000 lb. The main body of the buoy was manufactured of Softlite foam by the Gilman Corporation. The foam proved extremely durable and easy to work with during the experiment. The steel ballast below

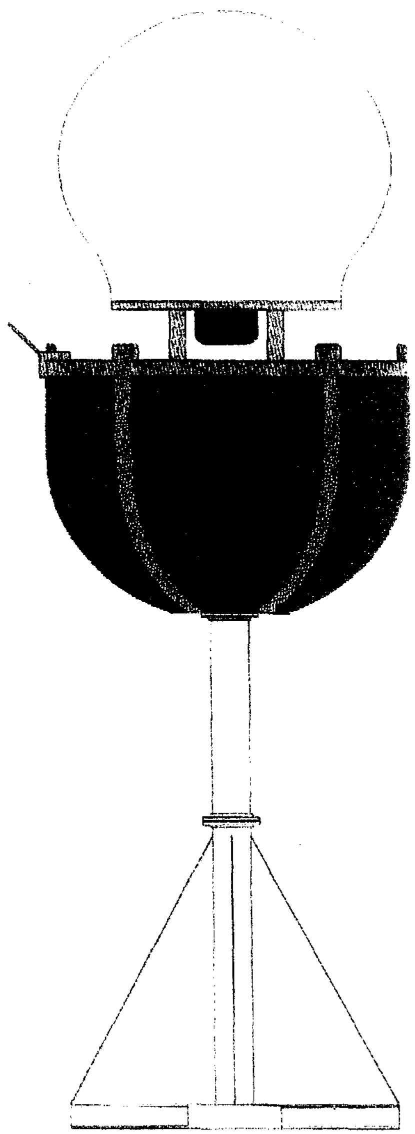

Figure 11. CAD Figure of Buoy

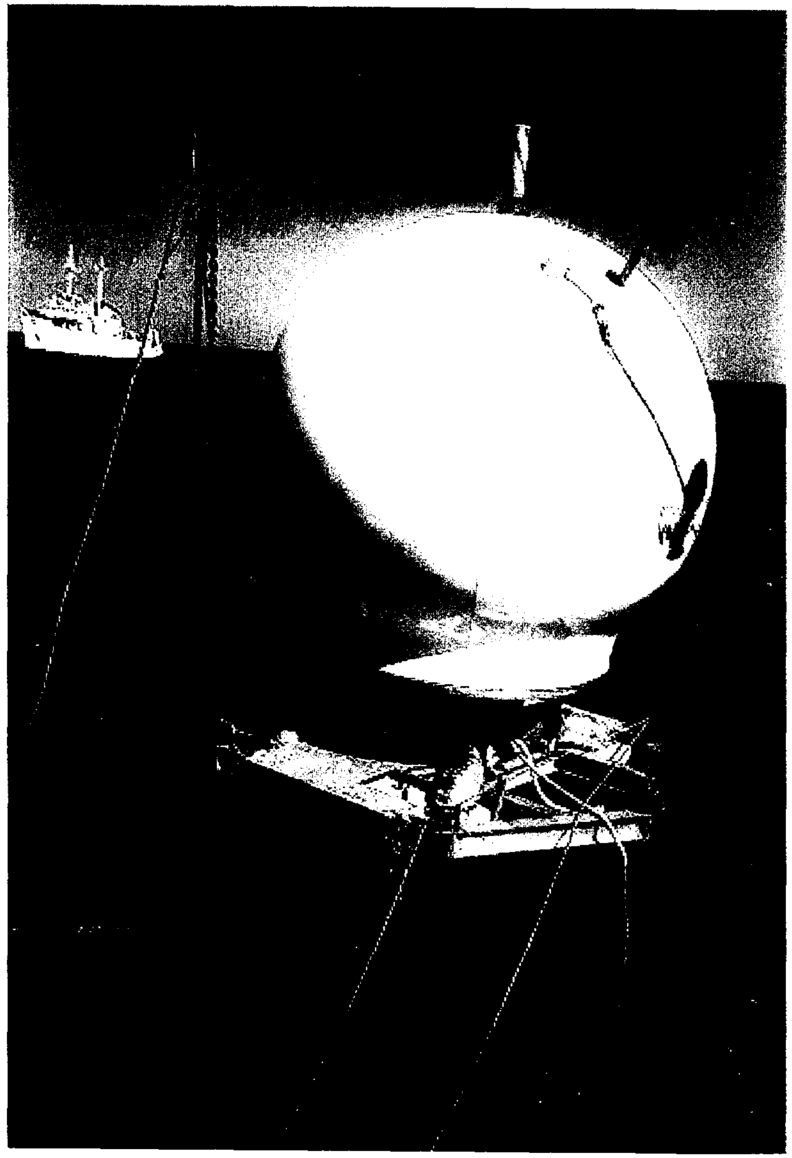

Figure 12. Photograph of Deployed Buoy

the foam served to improve stability characteristics. The fiberglass radome was added to gather information on the stability of the buoy if outfitted with a 1.4 m pointing antenna system as part of a commercial C-band SATCOM capability.

As described earlier, TESPEX II utilized a omni-directional antenna which was mounted on top of the radome. To approximate the weight and center of gravity of an antenna, pedestal and amplifier assembly, the diesel generator used to power the electronics and air conditioning was located inside the radome. The generator was a 6.8 KVA diesel that supplied three 20 amp 60 Hz, circuits. One circuit was used for each ELB, while the third circuit was used for the air conditioning. The buoy carries approximately 300 gallons of fuel, allowing for up to 30 days of continuous operation.

The ELBs designed to house the buoy electronics were waterproof aluminum cases housed in cavities cut into the top of the foam section of the buoy. This technique provided maximum protection for the electronics from shock during deployment, and protected the electronics from saltwater for the experiment. Each ELB had two 4" PVC couplings for connection to the A/C system. Cables between the two ELBs were run through the same ducting. Both ELBs had underwater mating connectors in the doors for connections outside the ELB, such as antenna, weather station, and power leads.

An addition to the buoy system for TESPEX II was the environmental sensor package. There was a justifiable amount of concern over equipment temperature within the sealed ELBs during system operation. (During system checkout, a component in the CIB panel overheated and was rendered useless.) Each ELB had a temperature sensor connected to the environmental station controller, which was connected to the buoy communication system via serial port. The SATCOM system relayed the temperature inside the ELBs and ambient temperature to the shore laboratory. Additional sensors monitoring barometric pressure and relative humidity were installed, as well as wind speed and direction sensors, for studying the wind loading effects of the 10 ft. diameter radome on the buoy. The equipment used for the sensors were two Sensormetrics ENV-50 systems (one WDT and one HUM module), which were inexpensive and allowed for simple software control from the main buoy program.

IV. TESPEX II - June/July 1994

Both TESPEX trials emphasized the role of the environment in signal processing, and the telemetry, via satellite, of the acoustic data. The several signal processing techniques investigated are all forms of what has become known as Matched-Field Processing (MFP). In MFP, an acoustic data base of some form is generated. This data base consists of elements, usually vectors of acoustic quantities referred to as replicas, which correspond to a source track or location. A source can then be located or tracked by matching (correlating) observations to the replica elements of the data base.

The data collected during TESPEX I and TESPEX II is being used by scientists involved in TTCP to determine whether significant passive sonar performance gains using new processing techniques [1,2] that capitalize on environmental complicity in coastal water can be realized. Scientific results related to the data analysis and the signal processing techniques are available from a variety of references [3,4].

TESPEX II involved both the 4-channel and the 32-channel SVLA. The 4 channel system (SVLA-4) was housed in the Bumble Bee buoy and the 32 channel system (SVLA-32) used the NRL buoy. The prime power for the SVLA-4 was a block of Interstate marine 12 volt, lead acid storage batteries. The SVLA-4 was improved with the addition of a GPS unit used for inserting an accurate time stamp into the SVLA-4 data steam, which made the synchronization of events much more precise. During the course of the experiment, the SVLA-4 was "serviced" by the FRV Southern Surveyor, for the purpose of retrieving the data tapes and to check on the system status.

The SVLA-32 system saw many improvements over its predecessor, the SVLA-4. Greater real-time control of system parameters was achieved, and engineers responsible for all systems on the buoy were able to monitor it's performance in greater detail than previously possible. The use of a generator allowed for longer deployment times and significantly easier power budget constraints on the SATCOM subsystem. The addition of temperature sensors into the ELBs was an important safety measure, to prevent equipment damage from overheating if the cooling system failed.

Cooling of the ELBs was one of the major engineering challenges during TESPEX II. The design of the ELBs called for cooling to occur by surrounding the waterproof case in a circulating pool of sea water. Sea water temperatures in excess of 30°C at the test site made this solution unsatisfactory. Instead, an air conditioning unit was installed just below the base of the radome. The a/c unit was modified to support 4" ducting, and ducting was connected to the ELBs to create a closed loop a/c system. This approach maintained adequate cooling for most of the experiment, but the a/c unit was nearly destroyed by saltwater by the end of the test, and will need to be replaced.

There are a number of engineering upgrades planned for the system before any future deployments. The most important goal is to develop a satellite communication subsystem capable of transmitting all acoustics channels from the buoy to the shore site and directly to NRL. This will require a high data rate (T1 levels, 1.544 Mbps) link, and will require the use of commercial satellites. A high data rate link requires development of a pointing antenna system capable of operating on the buoy. Plans call for development of this asset in FY95, with an engineering test in the fall of 1995.

Other system enhancements are also anticipated. While the system performed quite satisfactorily, remote troubleshooting and diagnostic capabilities were limited, and working on the buoy while deployed was cumbersome at best, making on-site inspection, changes, and repairs difficult. Improvements in remote system access, both from the shore facility and from a support ship within LOS range (<13 miles), will help make the system more reliable and easier to maintain. Plans call for adding an LOS communication capability in FY95.

It is anticipated that modifications and improvements to the system will be made in the next few months and the system will be deployed in the fall of 1995. The performance goal for the future system will be to transmit 1.5 Mbps of acoustic data from the buoy directly to NRL, where scientists will both receive real-time acoustic data and control the SVLA system. It is anticipated that the future system will be able to operate remotely for a 30 days, with ship support required for deployment, recovery, and occasional LOS system control.

V. CONCLUSIONS

The SVLA-32 system used during TESPEX II was a breakthrough in the gathering of acoustic data. Researchers on land, with a full complement of diagnostic tools at their disposal, were able to acquire real-time acoustic data from an experiment. Project personnel could thus monitor the direction and effectiveness of the data collection process and make immediate test plan changes when necessary, without the time-consuming process of halting the experiment to retreive data. The expenses incurred in the development of the satellite data telemetry system were offset by the costs of shipborne operations, the opportunity for longer deployments, improvements in data quality, and the ability to re-use the SVLA equipment for other testing programs.

Follow-on efforts with the SVLA-32 system will expand the capability of the systems on the buoy and increase the data transfer rate. Near-term plans are to equip the buoy with a more flexible relay rack enclosure module, a diesel generator and an air conditioner for system cooling. In addition, system data rates will be increased to 1.544 MBPS (T1), full duplex, with a longer term goal of data rates in the 45 MBPS range.

VI. REFERENCES

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